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Effects of 1α-Hydroxycholecalciferol and Phytase on Growth Performance, Tibia Parameter and Meat Quality of 1- to 21-d-old Broilers*

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ABSTRACT : This experiment was conducted to investigate the effects of interaction between 1α-hydroxycholecalciferol (1α-OH D_3) and phytase on growth performance, parameters of tibia and plasma, and meat quality of 1- to 21-d-old broilers. Two hundred and forty male, 1-d-old Arbor Acres broilers were randomly assigned to 20 cages, with 12 chicks per cage. Five treatments were designed, with four cages each. A 2×2 factorial experiment was designed to test 0 and 5 μg/kg of 1α-OH D_3 in combination with 0 and 500 U/kg of phytase. A basal diet was formulated to contain 2.9 g/kg of non-phytate phosphorus (NPP), and the control diet was formulated to contain a normal level of NPP (4.5 g/kg). Results showed that 1α-OH D_3 alone increased tibia ash, contents of calcium and phosphate, breaking strength, concentrations of plasma calcium and phosphate, and water-holding capacity of breast and thigh meat, while it decreased growth of broilers. Phytase alone improved performance and tibia quality. Although growth of broilers was lower than that of the positive control when the diet was supplemented with 1α-OH D_3 and phytase, tibia quality was significantly improved by the addition of 1α-OH D_3 and phytase. These data suggest that interaction between 1α-OH D_3 and phytase at 2.9 g/kg of dietary NPP could significantly increase bone quality of 1- to 21-d-old broilers, while not improving growth performance. (**Key Words :** 1α-OH D_3, Growth, Tibia, Meat Quality, Broiler)

INTRODUCTION

In 1973, Haussler first reported that 1α-hydroxycholecalciferol (1α-OH D_3) could replace vitamin D_3 in chicken diets and further studies showed that the activity of the former is about 8 times of vitamin D_3 based on tibia ash (Boris et al., 1977; Edwards et al., 2002). Holick et al. (1976) and Edelstein et al. (1978) have found that 1α-OH D_3 metabolized quickly to 1,25-$(OH)_2D_3$ in intestinal membrane of chicks, and the latter is the active form of vitamin D_3. As the analog of vitamin D_3, 1α-OH D_3 has similar effect to facilitate growth and phytate phosphorus utilization of broilers (Biehl et al., 1995; Biehl and Baker, 1997a, b; Edwards, 2002; Snow et al., 2004). Whether 1α-OH D_3 has positive effect on meat quality of broilers is not known, although vitamin D_3 improved meat quality of swine and cattle (Swanek et al., 1999; Montgomery et al., 2000; Karges et al., 2001; Wiegand et al., 2002; Wilborn et al., 2004).

The phytase hydrolyzes phosphate groups from the phytin molecule potentially making the hydrolyzed phosphorus from phytin available to the animal. Previous studies have shown that dietary phytase improved growth performance, tibia ash, and phytate phosphorus (PP) utilization of broiler chicks (Lim et al., 2001; Guo et al., 2003; Shirley and Edwards, 2003; Singh et al., 2003; Selle et al., 2007).

Snow et al. (2004) reported that interaction between 1α-OH D_3 and phytase had positive effects on body weight gain (BWG) and PP release of 1- to 21-d-old broilers. However, non-phytate phosphorus (NPP) of basal diet was low (1.3 g/kg) in their experiment and growth was lower than those of broilers fed normal-P diet (Snow et al., 2004). In the study of Driver et al. (2005b), tibia ash content was significantly lower than those of broilers fed normal NPP diet, although BWG was equivalent to the control group when 1α-OH D_3 and phytase were supplemented together.

The objective of this experiment was to determine

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Table 1. Composition of experimental diets

Ingredient (g/kg)	Basal diet	Control diet
Corn	624.1	616.2
Soybean meal	291.4	291.4
Soybean oil	10.0	10.0
Swine lard	2.6	5.4
Corn gluten meal	32.0	33.1
Limestone	19.6	13.8
Dicalcium phosphate	9.7	19.5
L-lysine	2.1	2.1
DL-methionine	1.6	1.6
Vitamin premix[1]	0.4	0.4
Trace mineral premix[2]	1.5	1.5
Choline chloride	2.0	2.0
Sodium chloride	3.0	3.0
Calculated composition (g/kg)		
AME (MJ/kg)*	12.25	12.25
AME (kcal/kg)*	2,928	2,928
CP*	200.0	200.0
CP**	203.0	201.0
Ca*	10.0	10.0
Ca**	11.4	11.4
Total P*	5.2	6.9
Total P**	5.0	6.7
Phytate P*	2.3	2.4
Phytate P**	2.4	2.4

[1] Vitamin premix provided the following (per kg of diet): vitamin A, 8,000 IU; vitamin D_3, 5 μg; vitamin E, 20 mg; menadione, 0.5 mg; thiamine, 2.0 mg; riboflavin, 8.0 mg; niacin, 35 mg; pyridoxine, 3.5 mg; vitamin B_{12}, 0.01 mg; pantothenic acid, 10.0 mg; folic acid, 0.55 mg; and biotin, 0.18 mg.

[2] Trace mineral premix provided the following (per kg of diet): iron, 100 mg; zinc, 100 mg; copper, 8 mg; manganese, 120 mg; iodine, 0.7 mg; and selenium, 0.3 mg.

* Calculated value. ** Determined value.

effects of interaction between 1α-OH D_3 and phytase on growth performance, tibia parameter, and meat quality at 2.9 g/kg of dietary NPP in 1- to 21-d-old broilers.

MATERIALS AND METHODS

Birds, diets, feeding and management

All procedures used in this study were approved by the Animal Care Committee of the Northwest Agriculture and Forestry University.

On the day of hatch, 240 male Arbor Acres chicks were individually weighed and were randomly and equally assigned to 20 cages (68×66×33 cm), with 12 chicks per cage. Five treatments were designed, with four cages each. A 2×2 factorial experiment was designed to test 0 and 5 μg/kg of 1α-OH D_3 in combination with 0 and 500 U/kg of phytase. A basal diet (Table 1) was formulated to contain 2.9 g/kg of NPP, and the control diet was formulated to contain a normal NPP (4.5 g/kg).

The birds were given access to mash feed and water *ad libitum* during the 21-d experiment. The lighting program consisted of 23 h light from d 0 to 3, 20 h of light from d 4 to 14, and 18 h of light from d 15 to 21. The room temperature was controlled at 33°C from d 0 to 3 and then gradually reduced by 3°C per week to a final temperature of 24°C.

1α-Hydroxycholecalciferol

The compound 1α-OH D_3 was kindly supplied by Taizhou Healtech Chemical Co., Ltd. (Taizhou, China). The 1α-OH D_3 solution was prepared by the method of Biehl and Baker (1997b). Briefly, 1α-OH D_3 was dissolved in ethanol, and then brought to a final concentration of 20 mg/L of 1α-OH D_3 in a solution of 5% ethanol and 95% propylene glycol.

Microbial phytase

Microbial phytase, derived from *Trichoderma strain* and expressed in the *Yeast Pichia Pastoris*, was kindly supplied by Guangdong VTR Bio-Tech Co., Ltd. (Zhuhai, China). The product was determined to have 5,000 U/g of phytase, where 1 U is equivalent to one phytase unit and is the amount of enzyme that liberates 1 μmol of inorganic P per min from 0.0051 mol/L sodium phytate at 37°C and at pH 5.50. The enzyme was added to the diet in powder form by serial dilution, and all diets were fed as mash.

Collection of samples

Excreta samples were collected from beneath each cage between d 17 and 21 (Dilger et al., 2004), dried at 65°C for 24 h, and ground to pass through a 1-mm mesh screen. On d 21, all broilers were weighed individually. For collection of blood and tibias, two chicks were randomly selected from each replicate and weighed (Viveros et al., 2002). Blood samples of 5 ml were collected by cardiac puncture, immediately centrifuged for 10 min at 3,000×g at 20°C, and frozen at -20°C. Birds were killed by cervical dislocation. The left and right tibias from individual birds were excised, sealed in plastic bags, and stored at -20°C for further analysis.

Chemical analysis

To determine the sample DM, a 5.0-g sample was placed into a drying oven at 100°C for 24 h. Phytate phosphorus and tP were determined by using the method of Rutherfurd et al. (2004). Crude protein was determined by the Kjeldahl method with a Kjeltec 2300 analyzer (Foss Tecator AB, Hoganas, Sweden). Energy contents of diet and excreta were determined by an automatic bomb calorimeter (Shimadzu Corporation, Tokyo, Japan).

For determination of tibia weight, fat was first removed from the tibias by a 36-h Soxhlet extraction in ethyl alcohol, followed by a 36-h extraction with diethyl ether, and then

dried at 100°C for 24 h. Tibia ash content was determined by ashing the bones in a muffle furnace for 18 h at 600°C. Tibia breaking strength was determined with an all-digital electronic universal testing machine (Shenzhen Hengen Instrument Co., Ltd., Shenzhen, China) fitted with a 3-point-bend rig with a load cell capacity of 50 kg, a crosshead speed of 10 mm/min, and a span over which the bone was set of 40 mm. Plasma calcium, inorganic phosphate (Pi), and total protein were determined with a Shimadzu CL-8000 analyzer following the manufacturer's instructions (Shimadzu Corporation, Tokyo, Japan).

Meat quality measurement

Tissue samples were removed from the right breast and thigh muscle for pH, color, water-holding capacity (WHC), and shear force (SF) determination. According to the method of Lu et al. (2006), when broilers were killed, breast and thigh muscle pH was tested at a depth of 0.5 cm below the surface using a pH meter (model PHS-3C, Shanghai Precision and Scientific Instrument Co., Ltd., Shanghai, China).

According to the method of McLaughlin et al. (1989), WHC was determined with a water-holding capacity meter (model YYW-2, Nanjing Soil Instrument Factory Co., Ltd., Nanjing, China) by placing a slice of weighed wet muscle (3 to 4 mm thick and 2 cm in diameter) between multiple layers of filter paper on a pressure plate, subjecting the tissue to 15 kg of pressure for 5 min, and then weighing the dry muscle again. The formula used for calculating WHC was as follows:

Water-holding capacity (%)
= ((wet weight (g)-dry weight (g))/wet weight (g)×100

The color values of lightness (L*), redness (a*), and yellowness (b*) were measured on the raw muscles by a WSC-S chroma meter (Shanghai Precision and Scientific Instrument Co., Ltd., Shanghai, China).

Shear force of the breast and thigh raw meat was measured by using a C-LM3 digital meat tenderness meter (Northeast Agricultural University, Harbin, China) with a 15-kg-load transducer and a crosshead speed of 200 mm/min. Adjacent 3.0-cm-long, 1.0-cm-wide, and 1.0-cm-thick strips were cut from the medial portion of the muscle, parallel to the longitudinal axis of the myofibres, and sheared according to the procedure described by Honikel (1998). The muscle was cut perpendicular to the muscle fiber orientation.

Statistical analysis

Experimental data were analyzed statistically by general linear model (GLM) and two way ANOVA procedures of SAS software (SAS Institute, 2001) as factorial experiments with all statements of significance ≤0.05 unless indicated otherwise.

RESULTS

Growth performance

Compared with those of birds fed basal diet, supplementing 5 μg/kg 1α-OH D_3 alone negatively affected BWG ($p = 0.041$) and feed intake (FI) ($p = 0.002$), while addition of 500 U/kg phytase alone in the basal diet significantly improved BWG ($p = 0.003$) and FI ($p<0.001$) of 1- to 21-d-old broilers (Table 2). However, combination of 5 μg/kg of 1α-OH D_3 and 500 U/kg of phytase in the basal diet yielded a better of BWG and FI than those of the basal diet group, but lower than those of supplementing phytase alone and control group, suggesting that 1α-OH D_3 and phytase have different mechanisms of affecting BWG

Table 2. Effect of 1α-OH D_3 and phytase on growth of 1- to 21-d-old broilers

NPP[1] (g/kg)	Phytase (U/kg)	1α-OH D_3 (μg/kg)	BWG[2] (g/bird)	FI[3] (g/bird)	BWG:FI (g:g)
2.9	0	0	451.06 [cd]	820.31 [c]	0.55
2.9	0	5	420.55 [d]	775.02 [c]	0.54
2.9	500	0	500.28 [ab]	970.05 [a]	0.52
2.9	500	5	470.46 [bc]	871.24 [b]	0.54
4.5	0	0	532.71 [a]	974.88 [a]	0.55
SEM[4]			10.23	19.39	0.01
Main effect means					
	0		435.81	797.66	0.55
	500		485.37	920.64	0.53
		0	475.67	895.18	0.53
		5	445.51	823.13	0.54
Source of variation			p		
Treatments			<0.001	<0.001	0.434
Phytase			0.003	<0.001	0.204
1α-OH D_3			0.041	0.002	0.586
Phytase×1α-OH D_3			0.980	0.166	0.279

[1] NPP = Non-phytate phosphorus, [2] BWG = Body weight gain, [3] FI = Feed intake, [4] SEM = Standard error of mean.

Table 3. Effect of 1α-OH D_3 and phytase on tibia parameters of 21-d-old broilers

NPP [1] (g/kg)	Phytase (U/kg)	1α-OH D_3 (μg/kg)	Ash		Strength (N)	Ca (%)	P (%)
			(g)	(%)			
2.9	0	0	0.48 [b]	35.81 [b]	48.71 [b]	12.32 [ab]	4.86 [c]
2.9	0	5	0.48 [b]	41.10 [ab]	56.56 [b]	14.82 [a]	5.71 [c]
2.9	500	0	0.54 [b]	37.20 [b]	51.44 [b]	12.76 [ab]	5.28 [c]
2.9	500	5	0.74 [a]	46.54 [a]	106.97 [a]	15.18 [a]	10.78 [a]
4.5	0	0	0.61 [b]	40.57 [ab]	63.62 [b]	11.69 [b]	8.15 [b]
SEM [2]			0.03	1.15	6.16	0.50	0.57
Main effect means							
	0		0.48	38.45	52.64	13.57	5.29
	500		0.64	41.87	79.20	13.97	8.03
		0	0.51	36.50	50.08	12.54	5.07
		5	0.61	43.82	81.77	15.00	8.24
Source of variation			p				
Treatments			0.003	0.013	0.003	0.076	<0.001
Phytase			<0.001	0.042	0.019	0.561	<0.001
1α-OH D_3			0.020	<0.001	0.007	0.003	<0.001
Phytase×1α-OH D_3			0.020	0.202	0.031	0.952	<0.001

[1] NPP = Non-phytate phosphorus, [2] SEM = Standard error of mean.

and FI in young broilers. As for gain-to-feed ratio, 1α-OH D_3 and phytase had no synergized effect.

Parameters of tibia and plasma

As shown in Table 3, ash weight (p = 0.020) and content (p<0.001), breaking strength (p = 0.007), and Ca (p = 0.003) and P content (p<0.001) of tibia were increased by 1α-OH D_3 supplementation. And phytase addition also improved all parameters of tibia except of Ca content. Interactions between 1α-OH D_3 and phytase were observed for tibia ash weight (p = 0.020), breaking strength (p = 0.031), and P content (p<0.001). The combination of 1α-OH D_3 and phytase provided higher tibia ash weight (p = 0.003) and content (p = 0.013), breaking strength (p = 0.003), and P content (p<0.001) than those of birds fed normal P diet (NPP 4.5 g/kg).

Supplementation of 1α-OH D_3 increased plasma Ca concentration (p = 0.026) (Table 4). Other parameters of plasma were not significantly affected by addition of 1α-OH D_3, phytase, or both of them. Total protein content lowered in normal-P diet than that of basal diet (p = 0.018).

Meat quality

Water-holding capacity of breast meat was increased with addition of 1α-OH D_3 (p = 0.001), and the combination of 1α-OH D_3 and phytase generated higher WHC than that of basal diet treatment (p = 0.009) (Table 5).

Addition of 1α-OH D_3 also enhanced WHC of thigh meat (p = 0.021) (Table 6). Compared with the basal diet, either supplement of 1α-OH D_3 or phytase yielded a lower

Table 4. Effect of 1α-OH D_3 and phytase on plasma parameters of 21-d-old broilers

NPP [1] (g/kg)	Phytase (U/kg)	1α-OH D_3 (μg/kg)	Ca (mg/100 ml)	Pi [2] (mg/100 ml)	Total protein (g/L)
2.9	0	0	6.81	6.78	33.10 [a]
2.9	0	5	8.68	8.37	30.85 [ab]
2.9	500	0	7.54	7.53	33.30 [a]
2.9	500	5	8.70	8.37	31.63 [a]
4.5	0	0	7.93	6.60	27.55 [b]
SEM [3]			0.33	0.32	0.66
Main effect means					
	0		7.75	7.57	31.98
	500		8.12	7.95	32.46
		0	7.18	7.15	33.20
		5	8.69	8.37	31.24
Source of variation			p		
Treatments			0.327	0.236	0.018
Phytase			0.541	0.628	0.664
1α-OH D_3			0.026	0.130	0.098
Phytase×1α-OH D_3			0.562	0.628	0.797

[1] NPP = Non-phytate phosphorus, [2] Pi = Inorganic phosphate, [3] SEM = Standard error of mean.

Table 5. Effect of 1α-OH D_3 and phytase on breast meat quality of 21-d-old broilers

NPP [1] (g/kg)	Phytase (U/kg)	1α-OH D_3 (μg/kg)	L value	a value	b value	SF [2] (N)	WHC [3] (%)	pH
2.9	0	0	42.06	14.52	24.45	25.30	4.30 [c]	6.52
2.9	0	5	42.27	16.31	23.09	20.68	6.70 [a]	6.53
2.9	500	0	42.26	16.41	25.01	20.02	4.03 [c]	6.56
2.9	500	5	43.03	17.23	26.04	25.73	6.04 [ab]	6.48
4.5	0	0	40.38	16.52	23.76	23.85	4.57 [bc]	6.53
SEM [4]			0.52	0.38	0.60	1.25	0.32	0.02
Main effect means								
	0		42.16	15.42	23.77	22.99	5.50	6.53
	500		42.65	16.82	25.52	22.87	5.03	6.52
		0	42.16	15.46	24.73	22.66	4.17	6.54
		5	42.65	16.77	24.56	23.20	6.37	6.51
Source of variation			p					
Treatments			0.631	0.240	0.626	0.509	0.009	0.661
Phytase			0.680	0.129	0.115	0.971	0.391	0.846
1α-OH D_3			0.674	0.154	0.874	0.866	0.001	0.371
Phytase×1α-OH D_3			0.812	0.586	0.270	0.127	0.709	0.231

[1] NPP = Non-phytate phosphorus, [2] SF = Shear force, [3] WHC = Water-holding capacity, [4] SEM = Standard error of mean.

SF. However, a synergized effect (p = 0.021) on SF was observed between 1α-OH D_3 and phytase, which was even higher than that of positive control group (NPP 4.5 g/kg).

Color (L, a, and b value) and pH of breast and thigh meat were not affected by 1α-OH D_3 or phytase supplementation.

DISCUSSION

Growth performance

Addition of 1α-OH D_3 to the basal diet had negative effects on BWG and FI in this experiment, which indicated that 1α-OH D_3 could not improve growth performance of broiler chicks when basal dietary NPP is up to 2.9 g/kg and vitamin D_3 is abundant. Edwards et al. (2002) reported that in basal diet with tP of 7.0 g/kg and without vitamin D_3, 1α-OH D_3 improved BW of 1- to 16-d-old broilers. However, when vitamin D_3 was enough (Biehl et al., 1997c) or dietary NPP reached 3.0 g/kg (Edwards, 2002), growth of broilers was not improved by 1α-OH D_3 addition. Why 1α-OH D_3 negatively influenced the growth of broilers when dietary NPP reached about 3.0 g/kg should be further studied.

Growth of 1- to 21-d-old broilers was increased by addition of phytase, which was similar to those of birds fed normal P diet (NPP 4.5 g/kg) in this experiment. Qian et al. (1997) found that phytase improved BWG and FI at dietary NPP of 2.7 g/kg and effects of phytase on performance were influenced by Ca to P ratio. When dietary Ca to tP ratio was

Table 6. Effect of 1α-OH D_3 and phytase on thigh meat quality of 21-d-old broilers

NPP[1] (g/kg)	Phytase (U/kg)	1α-OH D_3 (μg/kg)	L value	a value	b value	SF[2] (N)	WHC[3] (%)	pH
2.9	0	0	42.03	15.15	21.20	45.22 [a]	4.22	6.54
2.9	0	5	40.99	17.03	21.89	31.08 [b]	5.75	6.60
2.9	500	0	41.90	16.75	21.35	30.13 [b]	4.90	6.61
2.9	500	5	41.01	16.83	20.26	35.50 [ab]	5.35	6.57
4.5	0	0	38.71	16.75	19.81	28.90 [b]	4.83	6.63
SEM[4]			0.48	0.29	0.34	1.99	0.24	0.01
Main effect means								
	0		41.51	16.09	21.55	38.15	4.99	6.57
	500		41.45	16.79	20.81	32.81	5.12	6.59
		0	41.96	15.95	21.27	37.67	4.56	6.57
		5	41.00	16.93	21.08	33.29	5.55	6.59
Source of variation			p					
Treatments			0.193	0.246	0.321	0.038	0.357	0.257
Phytase			0.956	0.286	0.389	0.173	0.717	0.521
1α-OH D_3			0.389	0.147	0.817	0.257	0.021	0.677
Phytase×1α-OH D_3			0.944	0.181	0.305	0.021	0.171	0.137

[1] NPP = Non-phytate phosphorus, [2] SF = Shear force, [3] WHC = Water-holding capacity, [4] SEM = Standard error of mean.

close to 1:1, phytase had little effects on growth of 1- to 16-d-old broilers (Driver et al., 2005a). It is deduced that phytase facilitates growth of broilers fed diet with higher Ca to tP ratio. In this study the Ca to tP ratio was 1.9:1 and growth performance was improved with addition of phytase.

The combination of 1α-OH D_3 and phytase did not significantly increase BWG, which might result from the negative effect of 1α-OH D_3 on growth of broilers. Previous study showed that, when dietary Ca and tP were 6.0 and 4.7 g/kg respectively, addition of 1α-OH D_3 and phytase enhanced growth of boilers, which was equivalent to those of control group (tP 6.8 g/kg) (Driver et al., 2005b). These data suggest that interaction for growth performance between 1α-OH D_3 and phytase might exist at lower level of Ca and P.

Parameters of tibia and plasma

Addition of 1α-OH D_3 increased tibia ash at dietary NPP of 2.9 g/kg in this experiment, which is agreed with the results reported by Biehl et al. (1995), Biehl and Baker (1997a, b), Edwards et al. (2002), and Snow et al. (2004). Tibia breaking strength and contents of Ca and P were also improved by 1α-OH D_3 supplementation. Edelstein et al. (1978) reported that 1α-OH D_3 metabolizes to 1,25-$(OH)_2$ D_3 in intestinal and bone tissue, and the latter facilitates the absorption and retention of calcium and phosphate (Tanaka et al., 1971, 1972; Tanaka and DeLuca, 1974), thereby improving tibia breaking strength.

Tibia ash, breaking strength, and P content were enhanced by phytase or NPP, and these results were similar to the reports by Lim et al. (2001), Shirley and Edwards (2003), Rama Rao et al. (2003), and Driver et al. (2005a). Research showed that phytase increased transit time of feed through the digestive tract (Watson et al., 2006) and improved phosphorus digestibility (Pham et al., 2008) and resulted in a greater FI and BW. In this experiment the positive response of phytase on tibia parameter may come from the improvement of intake of feed and phosphorus.

Previous studies showed that the combination of 1α-OH D_3 and phytase improved growth of starter broilers significantly, while tibia ash was lower than those of birds fed normal P diet (Snow et al., 2004; Driver et al., 2005b). However, in this experiment addition of 1α-OH D_3 and phytase together resulted in greater tibia ash and breaking strength compared with those of broilers fed normal P diet (NPP 4.5 g/kg), while growth was not improved by the combination of 1α-OH D_3 and phytase. Therefore, the level of dietary Ca and P should be further studied at which addition of 1α-OH D_3 and phytase together could improve both of growth and tibia quality.

Plasma Ca concentration increased and Pi content had the tendency to increase by addition of 1α-OH D_3, which was similar to those reported by Haussler et al. (1973) and Edwards (2002). These results indicated that 1α-OH D_3 facilitates absorption of Ca and Pi. There might be two ways of 1α-OH D_3 action on phosphorus: i) increasing NPP utilization by facilitating Pi absorption; ii) improving PP utilization by facilitating Ca absorption and decreasing the restriction of Ca on endogenous phytase. Data in our laboratory have shown that 1α-OH D_3 stimulates small intestinal NaPi-IIb cotransporter gene expression (Han et al., 2009) and facilitates Pi transport.

Plasma Ca, Pi, and total protein concentration were not affected by addition of phytase or both of them, while Shirley and Edwards (2003) and Bhanja et al. (2005) reported that dietary phytase had positive effect on plasma Pi concentration.

Meat quality

No report about 1α-OH D_3 on meat quality was found. In this experiment WHC of breast and thigh meat was increased by addition of 1α-OH D_3. Interaction between 1α-OH D_3 and phytase was observed for decreasing SF of thigh meat. These results indicated that meat qualities were improved by addition of 1α-OH D_3.

Researches in swine and cattle showed that dietary vitamin D_3 supplementation improved meat color (Wiegand et al., 2002; Wilborn et al., 2004), decreased SF (Swanek et al., 1999; Montgomery et al., 2000; Rider Sell et al., 2004), and increased WHC (Karges et al., 2001; Montgomery et al., 2004). Tenderization of meat might come from activation of calpain proteases because of the positive effect of vitamin D_3 on Ca absorption in intestine and reabsorption in kidney (Swanek et al., 1999). However, other researches showed that meat color of cattle (Reiling and Johnson, 2003) and SF of swine meat (Wiegand et al., 2002; Wilborn et al., 2004) were not affected by vitamin D_3 addition.

In summary, addition of 5 μg/kg of 1α-OH D_3 improved contents of tibia ash, Ca, and P, breaking strength, and water-holding capacity of breast and thigh meat. However, body weight gain and feed intake were decreased by 1α-OH D_3. When 500 U/kg of phytase was added to the basal diet, growth performance and tibia quality of broilers were improved. Synergized effect between 1α-OH D_3 and phytase was observed on tibia breaking strength, contents of tibia ash and P, and shear force of thigh meat.

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